CHAPTER 5

PLANETARY ORBITS AND CONFIGURATIONS

5-A. Introduction

The planets revolve around the Sun in orbits that lie nearly in the same plane. Therefore, the planets, with the exception of Pluto, are always found in the belt of the sky called the Zodiac, which is centered on the ecliptic and extends about 8^o on each side of it. (Pluto can be as much as 17^o away from the ecliptic.) Planets closer to the Sun than the Earth are classified as **Inferior planets.** Those planets farther from the Sun than the Earth are classified as **Superior Planets.** The apparent motion of a planet against the background stars depends on whether the planet is an inferior or a superior planet.

5-B. Elongation

The angular separation between the Sun and a planet as seen from the Earth and measured east or west along the ecliptic is called the planet's elongation.

Elongation is the angular distance of an object from the Sun.

It is important to remember that **eastern elongations are negative numbers** and **western elongations are positive numbers.**

Certain specific elongation values are given names called
***Aspects* or *Configurations*.**

When two objects are in the same direction as seen from the Earth (Elongation = 0^o), the aspect is **Conjunction.** When an object and the Sun are observed to be 90^o apart (Elongation = 90^o east or west) the object's aspect is **Eastern Quadrature** or **Western Quadrature.** When two objects are observed to be in opposite directions (Elongation = 180^o) the aspect is **Opposition.**

The diagram on the right depicts the plane of the Earth's orbit as viewed from the north ecliptic pole. Drawn in this plane are examples of the orbits of a superior planet and an inferior planet relative to the Earth's orbit. In such a diagram, elongation is the angle between a line drawn from the Earth to the Sun and another line drawn from the Earth to the planet that is to be observed. **The vertex of the elongation angle is always at the center of the Earth, not at the Sun**. In the same diagram, westward is defined to be in the clockwise direction and eastward is defined as counterclockwise.

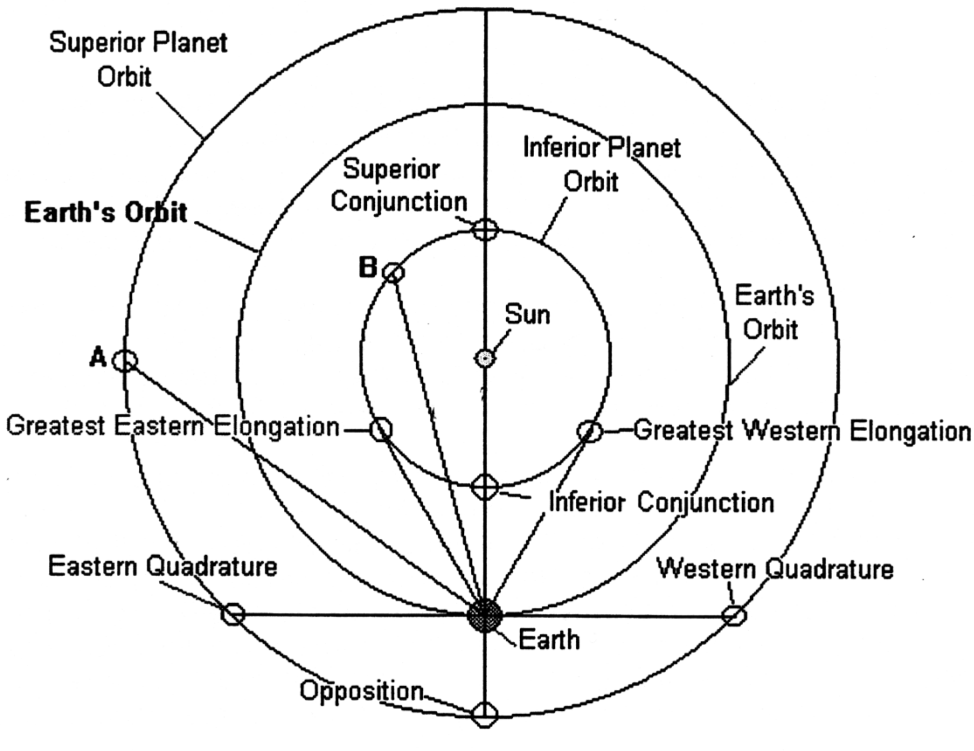

Fig. 5-1. Configuration or Aspects for inferior and superior planets.

For inferior planets, there is a maximum angular distance the planet can be observed from the Sun. This angle can be found by drawing a line from the center of the Earth to a point on the planet's orbit such that this line is perpendicular to a radius of the orbit. Such a line is called a tangent line. These maximum angles for an inferior planet are called **greatest eastern elongation** or **greatest western elongation.** They must always be less than 90^0. Since an inferior planet's orbit lies within the Earth's orbit, it can never be at opposition (Elongation = 180^0) or quadrature (Elongation = 90^0). However, an inferior planet has two types of conjunction. One is when the planet is closest to the Earth, i.e., between the Earth and the Sun. This is called an **inferior conjunction**. The other is when the planet is on the far side of the Sun. This is called a **superior conjunction**.

The motion of a superior planet carries it through a complete range of elongations, similar to the Moon. When a superior planet is at opposition, it is closest to the Earth, and when it is at conjunction (by the geometry a superior conjunction) it is farthest from the Earth.

Elongations should not exceed 180^o and therefore should be measured east or west of the Sun, whichever direction gives the smaller value of the elongation.

The diagrams below illustrate how the elongations of the planets may be drawn in a planar diagram similar to the one above. The first diagram shows the elongations for the inner planets and the second diagram does so for the outer planets. These diagrams have been taken from the software ***SKYLAB.***

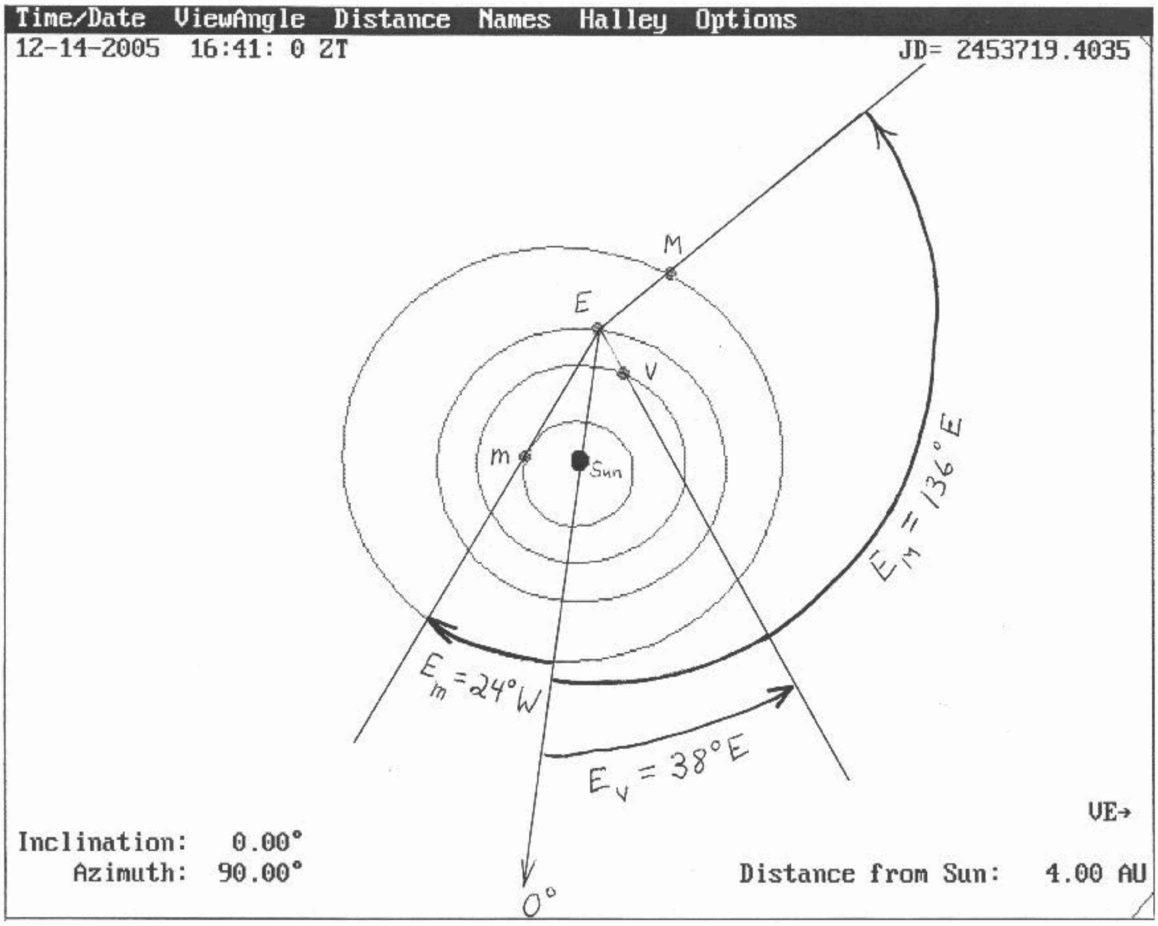

Fig. 5-2. A planar orbital view showing the elongation angles for the inner planets.

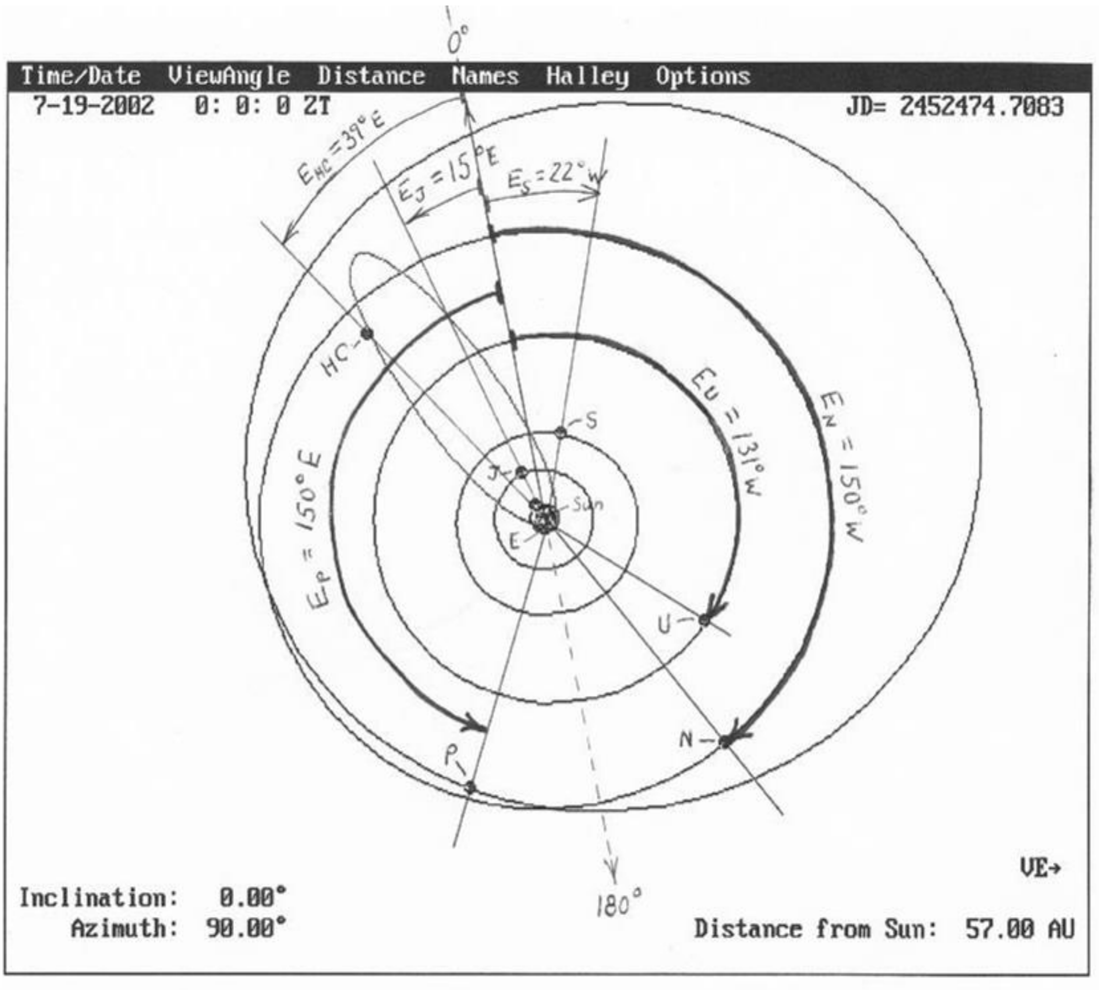

Fig. 5-3. Planar orbital view showing the elongations of the outer planets.

5-C. Calculating Planetary Events

There is a simple relation between a planet's elongation and the approximate time it will rise, make upper transit (UT), or set. This is:

$$\mathbf{T_P = T_{\odot} - T_E} \qquad (5\text{-B}.1)$$

The meaning of the symbols in the above equation is as follows:

$\mathbf{T_P}$ = Local Time when a planet will rise, make upper transit, etc.
$\mathbf{T_{\odot}}$ = Local Time for the corresponding solar event: rise, set, etc.
$\mathbf{T_E}$ = Planetary elongation in time units.

The value for T_E is found by dividing the elongation angle by the angular rate of rotation of the Earth. When a planet or body is west of the Sun, it is ahead of the Sun. When the body is east of the Sun, it is behind the Sun. You should be able to visualize this in the sky. If the elongation of a planet is measured eastward from the Sun, it must be a negative quantity in the above equation. Westward elongations are positive. If the answer comes out negative, add 24:00, and if the answer is greater than 24:00, subtract 24:00.

Equation (5-B.1) works best when the planet and the Sun are both near the celestial equator. For most problems, we can then assume that sunrise is 06:00, upper transit (UT) for the Sun is 12:00, and sunset is at 18:00. Do not use A.M. or P.M. in the above equation; use a 24 hour clock only. If the Sun, planet, or Moon is not near the celestial equator, the above equation may be off by more than an hour. The farther away one or both objects are from the celestial equator, the larger the error. The value of the **equation of time** (the difference between local apparent solar time and local mean solar time) is another factor that complicates matters here.

Assignment 5-C 1:

Run the Planetmation program in Skylab to determine the elongation of Venus on October 15 of this year and then use the above equation to compute what time Venus will set on this date. Submit a chart similar to Fig. 5-2 but showing the planets out to 2 AU, with a view-angle of 0^o (so that the view is perpendicular to the orbital planes). Draw the lines of sight and arc to indicate the elongation of Venus, as shown in the above diagrams. Do the calculation in the upper right or left corner of the chart, whichever provides less interference with drawing the elongation.

5-D. Retrograde Motion

One of the most difficult observable motions of the planets to explain by pre-Copernican models of the Solar System was their retrograde motions. When the superior planets were near opposition, they slowed down in their projected orbital motions on the celestial sphere and reversed course for a while, moving westward, which is considered to be the retrograde direction. They would then slow down again and reverse course and move eastward again. The latter direction is considered the prograde direction.

By simply replacing the Earth with the Sun as the center of the Solar System, the retrograde motions were easily explained. This was done by Copernicus in 1542. Fig. 5-4 schematically illustrates this.

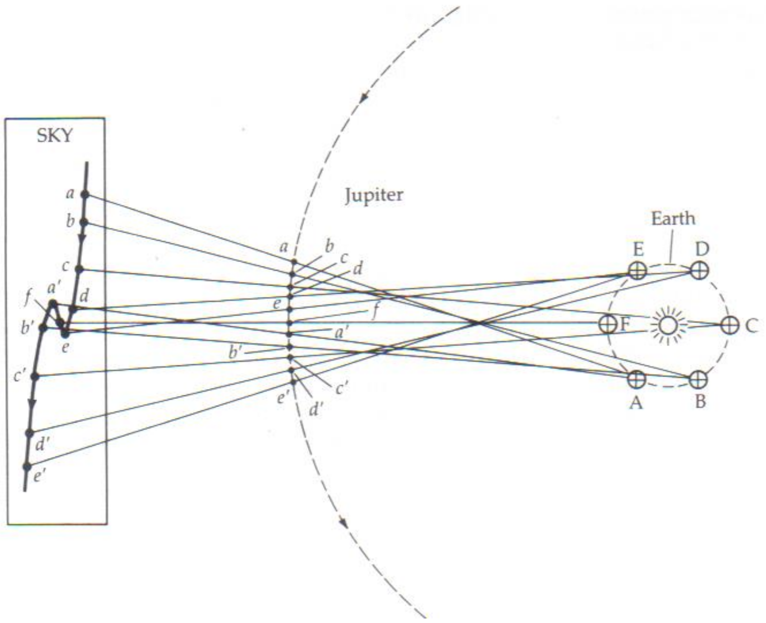

FIGURE 5-4 Retrograde motion in a heliocentric model. As the Earth passes a superior planet, that planet appears to move opposite its normal eastward direction with respect to the stars. Here the Earth passes Jupiter at point *Ff*, which marks the middle of the retrograde motion.

Assignment 5-D 1:

Trail Mars and then Jupiter separately in the SKYLAB program ***Skymation*** (not planetmation) to see these retrograde motions. Print out a separate chart for each planet and submit for credit. Start your trail in August 2011 for both planets. On the chart plot a grid and the stars. Also measure the elongation of each planet at the middle of the retrograde loop. You can use the reverse motion key to back up a planet in its orbit without ruining the trail to determine the date at the middle of the retrograde loop, which is the position labeled ***f*** in Fig. 5-4. Draw an arc on each chart for the elongation angle and label its value. This arc must be drawn along the ecliptic starting at the Sun and ending at the closest point to the planet.

5-E. Sidereal and Synodic Periods

The sidereal period of revolution is the time it takes for a body to complete and orbit of 360^o This period of time is determined observationally by using the stars as reference points. The Latin word for star is sidus and hence the term sidereal period. The Earth's sidereal period, **E**, is 365.2663 days. . We shall designate the sidereal period for a planet other than the Earth to be **P** in the discussion to follow.

The synodic period, **S**, is the time it takes a planet to move in its orbit and return to the same position in the sky relative to the Sun as seen from the Earth; in other words, to return to the same elongation. However, one must be careful about the retrograde motion. This is especially so for the inferior planets, since the same elongation can be ambiguous. For example, one must distinguish between inferior and superior conjunctions. For the superior planets, the synodic period is usually defined as the time between two successive oppositions. However, the retrograde motions complicate making this determination.

We now turn to deriving a relationship between **E, S, P**. The Earth moves in its orbit at an average rate of 360°/E degrees per day while any other planet moves at a rate of 360°/P degrees per day as viewed from the Earth. For a superior planet, the Earth completes one orbit and then it must traverse the additional angle S x (360°/P) in the time S-E to catch up to the superior planet at opposition again. This is schematically illustrated in Fig. 5-5 below. Hence,

$(S-E)(360^o/E) = S(360^o/P)$

This simplifies to :

$1/S = 1/E - 1/P$.

For an inferior planet

$1/S = 1/P - 1/E$

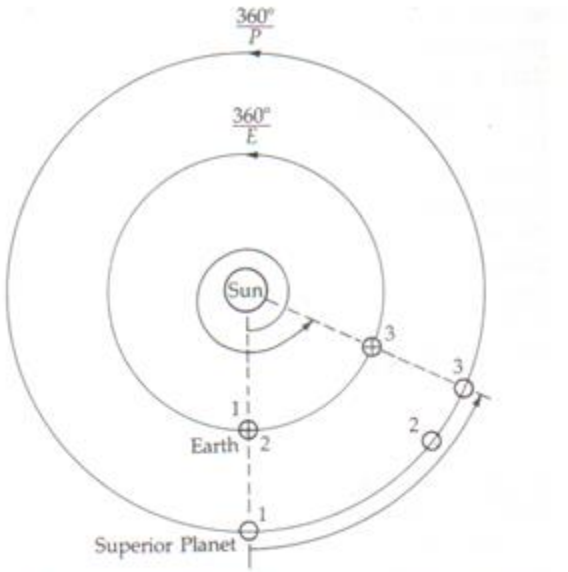

FIGURE 5-5 Synodic and sidereal periods in a heliocentric model. As the Earth orbits the Sun at an angular speed of 360°/*E* degrees per day, a superior planet moves at 360°/*P* degrees per day (as seen from the Sun). The Earth moves from position 1 to position 2 after one orbit and has *S* − *E* days to reach the next opposition (at position 3). During this time, the superior planet has moved from position 1 to position 3.

Assignment 5-E 1:

Trail Mars and then Mercury separately in the SKYLAB program ***Skymation*** to measure the length of their synodic and sidereal periods. Begin the trail on July 1 of this year. Print out a separate chart for each planet and each period and submit for credit. On each chart plot a grid and the stars.

5-F. Kepler's Laws of Planetary Motion

It was Johannes Kepler who discovered that the orbits of the planets were actually ellipses rather than circles. This discovery was made by analyzing the positional data for the planets made by the Danish astronomer Tycho Brahe, who was a colleague of Kepler. In fact, Kepler formulated three laws of planetary motion from his analysis. The first two laws were published 1609 and the third law in 1619.

These laws are:

1. All the planets revolve in elliptical orbits around the Sun, which is located at one of the foci of the ellipse.
2. The orbital radius vector of a planet sweeps out equal areas in the plane of its orbit in equal time intervals. The radius vector is the line connecting the Sun and the planet. This actually means that the angular momentum of the planet remains constant as it moves in orbit.
3. For each planet, the square of the sidereal period of revolution is proportional to the cube of its mean distance from the Sun. This referred to as the "Harmonic Law". This law implies the law of gravity, but it was up to Newton to show this.